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(54) Title: HIGH VOLTAGE INTEGRATED SWITCHING DEVICES ON A BONDED AND TRENCHED SILICON SUBSTRATE			
(57) Abstract			
<p>A high voltage integrated switching device includes at least one high voltage switching circuit, preferably employing DMOS technology and characterized by a breakdown voltage of at least 100 volts, on a dielectrically isolated, bonded and vertically trenched silicon substrate. Multiple high-voltage switching circuits may be located in close proximity on a single substrate without circuit breakdown or shorting during circuit operation. The circuit may further include one or more low- and/or intermediate-voltage circuits employing, for example, CMOS and bipolar technologies on the same silicon substrate and located in close proximity without voltage breakdown during circuit operation.</p>			

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HIGH VOLTAGE INTEGRATED SWITCHING DEVICES ON A BONDED AND TRENCHED SILICON SUBSTRATE

5 Technical Field

The present invention relates to high voltage integrated switching devices and to methods of fabricating several of such devices on a single silicon substrate.

Background of the Invention

10 The term "breakdown voltage", as used herein, means the voltage required to cause current to leak through a dielectric insulator, thereby causing a short circuit between inadequately dielectrically isolated devices or components. The term "high voltage", as used herein, means a device which has a breakdown voltage of at least 100 volts, and possibly much greater. The term "intermediate voltage", as used herein means a device
15 which has a breakdown voltage from approximately 20 volts up to approximately 100 volts. The term "low voltage", as used herein means a device which has a breakdown voltage less than and up to approximately 20 volts.

High-voltage switching applications in, for example, telephone central office switching stations generally require a large number of high-voltage switching circuits on a
20 single circuit board. The density and proximity of several high-voltage circuits on a single board requires adequate dielectric isolation between them to avoid shorting of the individual circuits.

High voltage circuits are preferably dielectrically isolated in both the vertical and lateral directions. Vertical isolation techniques are well known in the semiconductor
25 manufacturing industry, and adequate vertical isolation is not difficult to achieve. However, adequate lateral isolation in a relatively confined space has been much more difficult to achieve.

In the past, such dielectric isolation has generally been provided by locating the individual switching circuits a substantial lateral distance apart from one another and by
30 filling the inter-circuit spaces with a dielectric insulating material.

The higher the voltage rating of a device, the greater the dielectric isolation required between adjacent devices. To prevent premature breakdown of adjacent devices

due to the magnitude of the electric fields from each of the devices, a dielectric filler material is preferably used to fill the spaces between the devices. The breakdown voltage of a device is a function of the amount of dielectric material between adjacent high voltage devices. Using this isolation approach, optimal spacing of high voltage devices therefore
5 may require relatively great amounts of dielectric isolation material between and around them, and this in turn requires that the devices be more widely spaced apart over a larger area.

The use of bonded and vertically trenched silicon substrates in the fabrication of multiple high voltage devices allows adjacent devices to be spaced as closely as 3
10 micrometers from one another in the lateral direction. Vertical trenching processes are well known and disclosed in, for example, United States Patent No. 4,139,442 to Bondur et al. With anisotropic etching, the extent of material removal in the lateral direction can be more closely controlled and is generally less than the extent of material removal in the vertical direction. This is highly advantageous in controlling manufacturing costs and
15 increasing throughput in the fabrication of low voltage devices. However, such substrates have heretofore not been used in the fabrication of multiple high voltage devices.

It would therefore be advantageous to provide a high voltage integrated switching device which includes, for example, multiple high-voltage circuits or a variety of high-, medium- and low-voltage circuits, on a single bonded and vertically trenched silicon
20 substrate.

Summary of the Invention

According to one aspect of the invention, there is provided a high voltage integrated switching device, comprising a dielectrically isolated, bonded and vertically
25 trenched silicon substrate, and at least one high voltage switching circuit fabricated on the substrate. The high voltage switching circuit is characterized by a breakdown voltage of at least 100 volts or greater.

In a preferred embodiment, the high voltage switching circuit is a bidirectional switching circuit that is characterized by a breakdown voltage of at least 350 volts.

30 The high voltage switching circuit preferably employs double diffused metal oxide semiconductor (DMOS) technology.

The device can include one or more intermediate and/or low voltage circuits on the same substrate. In one embodiment the intermediate voltage circuit preferably employs bipolar technology, and the low voltage circuit preferably employs complementary metal oxide semiconductor (CMOS) technology.

5 According to another aspect of the invention, there is provided a method of making a high voltage integrated switching device. The method comprises the steps of:

 providing a bonded pair of silicon wafers separated by a layer of insulating silicon dioxide;

 forming a network of substantially vertical trenches in one wafer of the bonded pair
10 to define a plurality of silicon active regions, and dielectrically isolating the silicon active regions from one another;

 doping the silicon active regions with a dopant material of the same conductivity type to form tubs, each including a silicon wraparound layer having a relatively high concentration of that conductivity type on the floors and sidewalls of the tubs; and

15 fabricating at least one high voltage switching circuit in at least one of the silicon active regions.

 In one preferred embodiment, the step of fabricating the at least one high voltage switching circuit comprises the following steps:

 forming a layer of highly pure silicon dioxide over a silicon active region;

20 forming a layer of polycrystalline silicon over the silicon dioxide layer; exposing selected portions of the silicon dioxide and polycrystalline silicon layers;

 forming at least one p-type region within the exposed portions by implanting a p-type dopant therein;

 forming at least one n-type region within each of the p-type regions to define
25 source contacts for the high voltage circuit, and forming an n-type region bridging the silicon active region and the wraparound region, by implanting an n-type dopant therein, to define a drain contact for the high voltage circuit; and

 forming electrically conductive contact pads over each of the source and drain contacts of the high voltage circuit.

In one preferred embodiment, the p-type dopant includes an element selected from the group consisting of arsenic and phosphorus. The p-type dopant preferably, although not necessarily, includes boron.

5 The method can further include the steps of fabricating at least one of an intermediate voltage and/or a low voltage circuit in respective silicon active regions during fabrication of the high voltage switching circuit, and on the same substrate.

In one preferred embodiment, the step of fabricating the intermediate voltage circuit comprises the steps of:

10 forming at least one p-type region within the silicon active region by implanting a p-type dopant therein;

forming an n-type region within the p-type region to define an emitter, and forming an n-type region within the silicon active region outside of the p-type region to define a collector, the n-type region extending from the silicon active region to the n+ wraparound region;

15 forming a p+ region within the p-type region to define a base; and

forming electrically conductive contact pads over the collector, emitter and base of the bipolar circuit.

In one preferred embodiment, the step of fabricating the low voltage circuit preferably comprises the steps of:

20 defining an n-channel and a p-channel in respective adjacent silicon active regions;

forming at least one p-type region within the silicon active region of the n-channel by implanting a p-type dopant therein;

forming a layer of highly pure silicon dioxide on the surfaces of the p-type region and the silicon active regions of the n-channel and p-channel;

25 forming a layer of polycrystalline silicon over the silicon dioxide layer; forming at least one source contact and at least one drain contact in the p-channel by implanting a p-type dopant into selected portions of the p-channel;

forming at least one source contact and at least one drain contact in the n-channel by implanting an n-type dopant into selected portions of the n-channel;

forming an n-type region within each of the p-channel and the n-channel, the n-type region extending from a p-type region to the n+ wraparound region in each channel; and

5 forming electrically conductive contact pads over the source and drain contacts of the p-channel and n-channel.

According to yet another aspect of the invention, there is provided a high voltage integrated switching device which comprises:

a dielectrically isolated, bonded and vertically trenched silicon substrate; at least one high voltage switching circuit fabricated on the substrate; at least one intermediate
10 voltage circuit fabricated on the substrate; and at least one low voltage circuit fabricated on the substrate. The high voltage switching circuit preferably has a breakdown voltage of at least 100 volts. The intermediate voltage circuit preferably has a breakdown voltage of up to about 100 volts, and the low voltage circuit preferably has a breakdown voltage of up to about 20 volts.

15 In a preferred embodiment, the high voltage switching circuit comprises a bidirectional switching circuit and is characterized by a breakdown voltage of at least 350 volts or more.

In a preferred embodiment, the high voltage switching circuit employs DMOS technology, the intermediate voltage circuit employs bipolar technology, and the low
20 voltage circuit employs CMOS technology.

These and other objects and advantages of the invention will in part be obvious and will in part appear hereinafter. The invention accordingly comprises the apparatus possessing the construction, combination of elements and arrangement of parts which are exemplified in the following detailed disclosure, the scope of which will be indicated in
25 the claims.

Brief Description of the Drawings

For a fuller understanding of the nature and objects of the present invention, reference should be made to the following detailed description taken in connection with
30 the accompanying drawings, in which:

FIG. 1A is a simplified view of an etched silicon wafer in preparation for use as a traditional DI silicon substrate, as known in the prior art;

FIG. 1B is a simplified view of the etched silicon wafer of FIG. 1A, on which a polycrystalline layer is grown over the etched surface, as known in the prior art;

5 FIG. 1C is a simplified view of the silicon substrate of FIG. 1B, now inverted so that the polycrystalline silicon layer is on the bottom and the back side of the silicon wafer is exposed;

FIG. 1D is a simplified view of the silicon substrate of FIG. 1C, in which the exposed silicon has been polished to define individual active regions of silicon separated
10 by polycrystalline silicon regions, as known in the art;

FIG. 1E is a simplified view of the construction of a bonded and vertically trenched silicon substrate, as known in the art;

FIG. 2 is a simplified view of one embodiment of a high voltage integrated switching device, including intermediate, low and high voltage circuits employing,
15 respectively, bipolar, CMOS and DMOS technologies, in which p-type regions are formed within the DMOS circuit and the n-channel of the CMOS circuit, all in accordance with the present invention;

FIG. 3 is a simplified view of one embodiment of the bipolar, CMOS and DMOS circuits of FIG. 2, in which an insulating silicon dioxide layer and polycrystalline silicon
20 layer are formed;

FIG. 4 is a simplified view of one embodiment of the bipolar, CMOS and DMOS circuits of FIG. 3, in which p-type regions are grown within the DMOS circuit, and a base for the bipolar circuit is grown;

FIG. 5 is a simplified view of one embodiment of the bipolar, CMOS and DMOS
25 circuits of FIG. 4, in which the source and drain for the p-channel of the CMOS circuit are grown;

FIG. 6 is a simplified view of one embodiment of the bipolar, CMOS and DMOS circuits of FIG. 5, in which the source and drain of the n-channel of the CMOS and DMOS circuits, and the collector and emitter of the bipolar circuits, are grown;

30 FIG. 7 is a simplified sectional view of one embodiment of a completed high voltage circuit employing DMOS technology in accordance with the present invention;

FIG. 8 is a simplified sectional view of one embodiment of a completed intermediate voltage circuit employing bipolar technology; and

FIG. 9 is a simplified sectional view of one embodiment of a completed low voltage circuit employing CMOS technology.

5

Detailed Description of the Drawings

The present invention allows multiple high-voltage integrated circuits having a breakdown voltage of at least 100 volts, and in particular devices having a breakdown voltage of at least 350 volts or greater, to be fabricated in relatively close proximity on a
10 single silicon substrate, without shorting of the circuits or breakdown of the dielectric material between the circuits and circuit components during operation. Sufficient lateral dielectric isolation between the individual integrated circuits is provided by using bonded and vertically trenched and dielectric-filled silicon wafers.

One or more low and/or intermediate voltage integrated circuits may also be
15 fabricated with the high voltage circuits on the same substrate using, for-example, CMOS and bipolar technologies.

Traditional dielectric isolation is achieved in the prior art by etching a silicon wafer
10 with an acid or suitable etchant on one side of the wafer according to a predetermined pattern to form several depressions or valleys 12 in the wafer, as shown in FIG. 1A. The valleys have sloped sides due to the wet-etch characteristics of common etchants, which
20 etch the silicon along crystal planes. The etched regions of the silicon are then doped with a high concentration of silicon of the complementary conductivity type, i.e., n⁺ in n-type silicon, or p⁺ in p-type silicon, to form an n⁺ or p⁺ wraparound region. The etched region is then lined with a dielectric material such as, for example, silicon dioxide. A
25 polycrystalline silicon layer 14 is then grown over the etched side of the wafer 10 to provide a convenient means of handling the wafer, as shown in FIG. 1B. The back side of the wafer 10 is then polished to the level of the polycrystalline silicon layer 14, as shown in FIG. 1C, to produce individual silicon active regions 16 having sloped sidewalls 18, as shown in FIG. 1D. Each active region 16 is separated from its adjacent neighbor by a
30 triangular region 13 of insulating polycrystalline silicon which is thickest at its base and thinnest at the surfaces of the active regions.

As evident from FIG. 1D, traditional DI substrates are relatively space-inefficient, due to the sloped sides characteristic of common wet-etching processes. In addition, if high voltage devices are to be fabricated in the active regions 16, they must be adequately laterally spaced and filled with sufficient dielectric material to avoid shorting and breakdown during operation. This may require that each active region 16 created in the fabrication of the high voltage device be limited to a region between the dotted lines provided by the triangular region in FIG. 1D, to add additional insulation in the regions 16A between the active regions, as the space provided by the triangular region 13 may not be sufficiently dielectrically insulating for the particular devices being fabricated on opposite sides thereof. This causes the high voltage devices to be relatively far apart on the substrate and necessitates a larger substrate.

As shown in FIG. 1E, bonded and trenched silicon wafer substrates overcome the space efficiency problems of traditional DI substrates. A pair of silicon wafers 10A, 10B is bonded together on opposite sides of a silicon dioxide insulating interface layer 15. Anisotropic etching is employed to provide active regions of silicon 16 with substantially straight sidewalls 19. The active regions are separated by substantially vertical trenches 17 and therefore can be more closely spaced than on a traditional DI substrate.

The substantially vertical trenches between adjacent silicon active regions may be filled with a dielectric insulator 11, such as tetraethyl orthosilicate (TEOS) and/or polycrystalline silicon. These materials are especially desirable for use with silicon wafers because of their thermal coefficients of expansion are close to that of silicon, thereby reducing the possibility that the dielectric insulator between the active regions will crack from thermal stress. The substrate may further be annealed prior to fabrication of the integrated circuits thereon. Alternatively or in addition, multiple trenches 17' may be formed to provide extra dielectric isolation between the active regions. The width of the trenches 17 or 17', and therefore the thickness of the insulating material within the trenches and between adjacent active regions of silicon, is preferably selected to withstand the operating voltage of the highest rated voltage device on the substrate without breakdown during operation, so that none of the circuits on the substrate is susceptible to voltage breakdown and current leakage during operation.

The silicon wafer 10B in the bonded and trenched substrate is processed so as to have either an excess of electrons (n-type conductivity) or an excess of electron vacancies, or holes (p-type conductivity). The silicon is then doped in selected regions with various n- or p-type dopants which increase or decrease the numbers of electrons or holes, as
5 desired. P-type silicon is typically formed by doping the silicon with, for example, a boron-containing dopant so as to provide an excess of holes, whereas n-type silicon is typically formed by doping the silicon with a phosphorus- or arsenic-containing dopant so as to provide an excess of electrons. A p+ or n+ designation indicates a region in the silicon of relatively high concentration of the respective conductivity type, whereas a p- or
10 n- designation indicates a region in the silicon of relatively low concentration of the respective conductivity type. Although the FIGURES illustrate the silicon as n-type conductivity, they may be of either the n or p type, and the invention is considered to cover the use of silicon of either conductivity type.

As shown in FIG. 2, in accordance with the present invention, the junction-
15 receiving wafer 10B, which may be either n-type or p-type silicon, is masked and anisotropically etched in a predetermined pattern to form a plurality of substantially rectangular active regions 16 having substantially vertical sidewalls 19 and separated by substantially vertical trenches 17 filled with a dielectric material 11. Each active region 16 is preferably sufficiently deep enough to withstand the voltage of the device to be
20 fabricated therein without breakdown of the device or of the surrounding dielectric insulating material 11.

Each active region 16 includes a thin layer 20 of a relatively high concentration of the same conductivity type. The silicon of the junction-receiving wafer in the FIGURES is of the n-type, and therefore the so-called wraparound layer 20 is a high-concentration (n+)
25 region of n-type silicon. If a p-type silicon is used, the wraparound layer 20 is a high-concentration (p+) region of p-type silicon.

A thin oxide layer 21 (shown only over the trenches in the accompanying FIGURES, and exaggerated in size for clarity) is then grown on the exposed active silicon regions to passivate the exposed silicon.

30 A high-voltage integrated switching device can be fabricated with multiple high voltage switching circuits on a single bonded and vertically trenched substrate. Such high

voltage circuits can be relatively closely spaced, thus considerably reducing the real estate required for such a device. One or more intermediate and/or low voltage circuits, as well as other circuit components, may also be fabricated on the same substrate.

For convenience of illustration and explanation, FIGS. 2-6 illustrate the fabrication of intermediate, low and high voltage circuits employing, respectively, bipolar, CMOS, and DMOS technologies, on a single bonded and vertically trenched, dielectrically isolated silicon substrate. FIG. 7 illustrates in detail a completed DMOS circuit. FIG. 8 illustrates in detail a completed CMOS circuit. FIG. 9 illustrates in detail a completed bipolar circuit.

As shown in FIGS. 2-6, in accordance with one aspect of the invention, a bipolar circuit 22, a CMOS circuit 24 including an n-channel portion 24A and a p-channel portion 24B, and a DMOS circuit 25, can all be formed in a single fabrication process. As shown in FIG. 2, the n-type silicon in the bipolar circuit 22 and the n-channel 24A of the CMOS circuit 24 are selectively masked with a photoresistive material 28, etched with a suitable etchant, and then doped with a p-type dopant to form p-type regions or wells 26 within the n-type active regions of the bipolar and CMOS circuits. In FIG. 2, the photoresistive material 28 is shown as a dotted line to illustrate that it is only temporarily present at any given stage of fabrication. The photoresistive material is selectively applied and removed to a substrate several times during a fabrication process as the circuit components are formed according to a predetermined design.

The regions of the bipolar circuit 22 and the n-channel 24A of the CMOS circuit 24 which are to be doped with a p-type dopant are then exposed to a uniform, relatively low concentration of a boron-containing dopant, typically by exposing the unmasked portions of the silicon active region to a boron-containing gas. This doping step is preferably performed in a suitable atmosphere at an elevated temperature which is sufficient to provide a desired depth and level of conductivity in the silicon active region. The photoresistive material is then removed from the masked portions of the silicon by application of a suitable etchant thereto.

As illustrated in FIG. 3, after the p-type regions 26 have been formed in the bipolar and n-channel circuits, a highly pure silicon dioxide layer 30 is grown over all exposed surfaces. A layer of polycrystalline silicon 32 is then grown over the silicon dioxide layer

30. Photoresistive material 28 is applied to selected portions of the circuits to mask those regions in which the polycrystalline silicon is to remain after an etching process is performed. In the illustrated embodiment, the polycrystalline silicon 32 is masked in the n-channel 24A and p-channel 24B of the CMOS circuit, as well as in the DMOS circuit 25. The polycrystalline silicon in the bipolar portion of the switch is not masked, and therefore during the etching step, substantially all of the polycrystalline silicon in the bipolar region will be removed. The oxide layer 30 beneath the polycrystalline silicon layer 32 protects the underlying active silicon from damage from the etchant. The polycrystalline layer 32 over the DMOS and CMOS circuits acts as a mask for a subsequent doping of those regions and self-aligns the base of the DMOS circuit and the source and drain of the CMOS circuit, as illustrated in FIGS. 4 and 6 and detailed more fully below. The photoresistive material 28 is then removed by application of a suitable etchant.

As shown in FIG. 4, two p-type regions 26' are then formed in the DMOS circuit 25, and a p⁺ region 27 is formed within the p-type region 26 of the bipolar circuit. As previously described, a photoresistive material 28 is applied to the active silicon regions of the DMOS circuit, and to a portion of the p-type region 26 of the bipolar circuit, which are not to be doped. A polycrystalline silicon island 32 in the DMOS region acts as a mask for an area between the p-type wells formed therein. A relatively high concentration of a p-type dopant, preferably a boron-containing gas, is used, and the doping is performed in a suitable atmosphere at a suitable temperature as previously discussed for a sufficient time to achieve a desired depth and level, or concentration, of p-type conductivity in the silicon active region of the DMOS circuit and in the p-type region of the bipolar circuit.

As shown in FIG. 5, source and drain contacts 34, 36 for the p-channel 24B of the CMOS circuit 24 are formed in a separate implant step. The silicon active region of the p-channel of the CMOS circuit are doped with a p-type dopant, such as a boron-containing gas, under the conditions previously described to achieve a desired p-type depth and concentration in the silicon active region.

As shown in FIG. 6, n-type regions defining source and drain contacts 38, 40 for the n-channel of the CMOS circuit, and source and drain contacts 42, 44 for the DMOS circuit 25, are formed. In this step also, n-type regions defining the emitter 46 and

collector 48 for the bipolar circuit 22 are formed. The n-type source and drain contacts 38, 40 and the emitter 46 are formed in the respective p-type regions 26 formed in a previous fabrication step (discussed in connection with FIG. 2). An n-type bootstrap region 50 is also formed in the n- and p-channels 24A, 24B of the CMOS circuit, for connecting the p-type regions to the n+ wraparound regions 20 and for maintaining a desired minimum potential on the p-type regions.

Although not shown in the FIGS., in accordance with another aspect of the present invention, other components which are necessary to complete the DMOS, bipolar and/or CMOS circuits, including resistors, diodes and capacitors, can be formed during the fabrication of these principle circuits. For example, the base and source of the DMOS circuit also function as a diode. The silicon dioxide and polycrystalline silicon layers function as resistors, and the p-type well regions function as capacitors. Thus, all the necessary components that are required for proper operation of the DMOS, bipolar and/or CMOS circuits are fabricated in a single process.

As shown in FIGS. 7-9, a suitable insulating material, such as tetraethyl orthosilicate (TEOS) or phosphorus-doped silicon glass (PSG), is deposited over all exposed surfaces to form a relatively thick insulating "field" oxide layer 51 which passivates the circuits prior to the formation of electrically conductive contact pads.

FIG. 7 illustrates in detail one embodiment of the completed DMOS circuit 25. Electrically conductive source contact pad 52 and drain contact pad 54 are deposited over the respective source and drain contacts 42, 44 of the circuit.

FIG. 8 illustrates one embodiment of the completed bipolar circuit 22. Electrically conductive contact pads 56, 58, 60 are deposited over, respectively, the collector 48, the emitter 46, and the base 47 of the circuit.

FIG. 9 illustrates one embodiment of the completed CMOS circuit 24, including n-channel 24A and p-channel 24B. Electrically conductive contact pads 62, 64 are deposited over the p-type source and drain contacts 34, 36 of the p-channel 24B and over the n-type source and drain contacts 38, 40 of the n-channel 24A. An electrically conductive contact 66 to ground is formed over bootstrap region 50 in the n-channel 24A.

Each silicon substrate preferably includes multiple high-voltage integrated circuits in relatively close proximity to one another. In one preferred embodiment, the high-

voltage circuits are bidirectional switching circuits that employ DMOS technology and have a breakdown voltage of at least 100 volts, and more typically at least 350 volts or higher.

5 The substrate may additionally include one or more low- or intermediate-voltage integrated circuits. For example, a line card access switching device used in telephone switching applications may include multiple high-, intermediate- and low voltage integrated circuits on a single substrate using bipolar complementary double diffused metal oxide semiconductor (BCDMOS) technologies. The bipolar circuits may be transistors or switching circuits and typically have a breakdown voltage of up to about 100
10 volts. The CMOS circuits are typically logic circuits and have a breakdown voltage of up to about 20 volts. All three types of circuits are closely spaced on a single silicon substrate without exhibiting current leakage or inter-circuit breakdown during normal circuit operation.

A high-voltage integrated switching device can be made by suitably masking and
15 etching a bonded wafer silicon substrate to form substantially vertical trenches separating active regions on which individual high voltage circuits will be fabricated. The trenches are preferably of a width sufficient to withstand the operating voltages of the highest rated device or devices on the substrate without breakdown of the dielectric insulating material between adjacent devices. The silicon active regions are then passivated by forming an
20 insulating layer of silicon dioxide over them.

Suitable masking and doping is done to define a p-type region within the n-channel of a CMOS circuit, if present, and a p-type region within a bipolar circuit, if present. A highly pure silicon dioxide layer is grown over all exposed surfaces, and a polycrystalline silicon layer is grown over the silicon dioxide layer. Suitable masking and doping is done
25 to define two p-type regions in the DMOS circuit. Source and drain contacts are then formed in the p-channel of the CMOS circuit and the base contact of the bipolar circuit. Source and drain contacts for the DMOS circuit and the n-channel of the CMOS circuit are then formed, as well as the emitter and collector contacts of the bipolar circuit. A field oxide insulating layer is formed over all circuits, and electrically conductive contacts are
30 formed over the source and drain contacts of the DMOS and CMOS circuits and over the collector, base and emitter contacts of the bipolar circuit. The entire circuit is then

passivated with a suitable insulating material, such as, for example, silicon nitride.

The devices and methods of the present invention allow multiple high voltage circuits to be fabricated on a single bonded and trenched dielectrically isolated silicon substrate without dielectric breakdown of the substrate. Thus, significant reductions in
5 device size and fabrication costs are realized.

Because certain changes may be made in the above apparatus without departing from the scope of the invention herein disclosed, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted in an illustrative and not a limiting sense.

Claims

- 1 1. A high voltage integrated switching device, comprising:
2 a dielectrically isolated, bonded and vertically trenched silicon substrate; and
3 at least one high voltage switching circuit fabricated on the substrate,
4 wherein the high voltage switching circuit is characterized by a breakdown voltage
5 of at least 100 volts.
- 1 2. A high voltage integrated switching device according to claim 1, wherein the high
2 voltage switching circuit comprises a bidirectional switch and is characterized by a
3 breakdown voltage of at least 350 volts.
- 1 3. A high voltage integrated switching device according to claim 2, further
2 comprising at least one of the group consisting of an intermediate voltage circuit and a low
3 voltage circuit, wherein the intermediate voltage circuit is characterized by a breakdown
4 voltage of up to approximately 100 volts, and the low voltage circuit is characterized by a
5 breakdown voltage of up to approximately 20 volts.
- 1 4. A high voltage integrated switching device according to claim 3, wherein the high
2 voltage switching circuit employs double diffused metal oxide semiconductor (DMOS)
3 technology, the intermediate voltage circuit employs bipolar technology, and the low
4 voltage circuit employs complementary metal oxide semiconductor (CMOS) technology.
- 1 5. A method of making a high voltage integrated switching device, comprising the
2 steps of:
3 providing a bonded pair of silicon wafers separated by a layer of insulating silicon
4 dioxide;
5 forming a network of substantially vertical trenches in one wafer of the bonded pair
6 to define a plurality of silicon active regions separated by the trenches, and filling the
7 trenches between the silicon active regions with a dielectric insulating material to
8 dielectrically isolate the silicon active regions from one another, wherein the trenches are

9 sufficiently wide to withstand the operating voltage of the highest rated component of the
10 circuit without breakdown when filled with said dielectric insulating material;
11 doping the silicon active regions with a dopant material of the same conductivity
12 type to form a region of increased concentration of that conductivity type on the floors and
13 sidewalls of the silicon active regions; and
14 fabricating at least one high voltage switching circuit in at least one of the silicon
15 active regions, wherein the high voltage switching circuit is characterized by a breakdown
16 voltage of at least 100 volts.

1 6. A method according to claim 5, wherein the high voltage switching circuit
2 comprises a bidirectional switch and is characterized by a breakdown voltage of at least
3 350 volts.

1 7. A method according to claim 6, wherein the step of fabricating at least one high
2 voltage switching circuit comprises the further steps of:
3 forming a layer of highly pure silicon dioxide over a silicon active region;
4 forming a layer of polycrystalline silicon over the silicon dioxide layer;
5 exposing selected portions of the silicon active region below the silicon dioxide
6 and polycrystalline silicon layers;
7 forming at least one p-type region within the exposed portions of the silicon active
8 region by implanting a p-type dopant therein;
9 forming at least one n-type region within each of the p-type regions to define
10 respective source contacts for the high voltage circuit, and forming an n-type region
11 bridging the silicon active region and the region of increased concentration of the same
12 conductivity type in the silicon active region by implanting an n-type dopant therein; and
13 forming an electrically conductive contact pad over each of the source and drain
14 contacts.

1 8. A method according to claim 7, wherein the n-type dopant includes an element
2 selected from the group consisting of arsenic and phosphorus, and wherein the p-type
3 dopant includes boron.

1 9. A method according to claim 7, comprising the further steps of fabricating at least
2 one of the group consisting of an intermediate voltage circuit and a low voltage circuit in
3 respective silicon active regions while fabricating the high voltage switching circuit,
4 wherein the intermediate voltage circuit is characterized by a breakdown voltage of up to
5 approximately 100 volts, and the low voltage circuit is characterized by a breakdown
6 voltage of up to approximately 20 volts.

1 10. A method according to claim 9, wherein the high voltage switching circuit employs
2 DMOS technology, the intermediate voltage circuit employs bipolar technology, and the
3 low voltage circuit employs CMOS technology.

1 11. A method according to claim 10, wherein the step of fabricating at least one
2 intermediate voltage circuit comprises the steps of:
3 forming at least one p-type region within the silicon active region-by implanting a
4 p-type dopant therein;
5 forming an n-type region within the p-type region to define an emitter, and forming
6 an n-type region in the silicon active region outside of the p-type region to define a
7 collector, the n-type region extending from the silicon active region to the n+ wraparound
8 region;
9 forming a p+ region within the p-type region and spaced apart from the n-type
10 region to define a base; and
11 forming an electrically conductive contact pad over the collector, emitter and base.

1 12. A method according to claim 11, wherein the n-type dopant includes an element
2 selected from the group consisting of arsenic and phosphorus, and wherein the p-type
3 dopant includes boron.

1 13. A method according to claim 10, wherein the step of fabricating at least one low
2 voltage circuit comprises the steps of:
3 defining an n-channel and a p-channel in respective adjacent silicon active regions;
4 forming at least one p-type region within the silicon active region of the n-channel
5 by implanting a p-type dopant therein;
6 forming a layer of highly pure silicon dioxide on the surfaces of the p-type region
7 and the silicon active regions of the n-channel and p-channel;
8 forming a layer of polycrystalline silicon over the silicon dioxide layer;
9 forming at least one source contact and at least one drain contact in the p-channel
10 of the CMOS circuit by implanting a p-type dopant into selected portions of the p-channel;
11 forming at least one source contact and at least one drain contact in the n-channel
12 of the CMOS circuit by implanting an n-type dopant into selected portions of the n-
13 channel;
14 forming an n-type region within the p-channel and the n-channel, wherein the n-
15 type region extends from a p-type region to the region of increased level of p-type
16 conductivity in each channel; and
17 forming an electrically conductive contact pad over the source and drain contacts
18 of the p-channel and n-channel.

1 14. A method according to claim 13, wherein the n-type dopant includes an element
2 selected from the group consisting of arsenic and phosphorus, and wherein the p-type
3 dopant includes boron.

1 15. A high voltage integrated switching device, comprising:
2 a dielectrically isolated, bonded and vertically trenched silicon substrate;
3 at least one high voltage switching circuit fabricated on the substrate,
4 at least one intermediate voltage circuit fabricated on the substrate, and
5 at least one low voltage circuit fabricated on the substrate,
6 wherein the high voltage switching circuit is characterized by a breakdown
7 voltage of at least 100 volts, the intermediate voltage circuit is characterized by a
8 breakdown voltage of up to approximately 100 volts, and the low voltage circuit is
9 characterized by a breakdown voltage of up to approximately 20 volts.

1 16. A high voltage integrated switching device according to claim 15, wherein the high
2 voltage switching circuit is a bidirectional switching circuit and is characterized by a
3 breakdown voltage of at least 350 volts.

1 17. A high voltage integrated switching device according to claim 16, wherein the
2 high voltage switching circuit employs double diffused metal oxide semiconductor
3 (DMOS) technology, the intermediate voltage circuit employs bipolar technology, and the
4 low voltage circuit employs complementary metal oxide semiconductor (CMOS)
5 technology.

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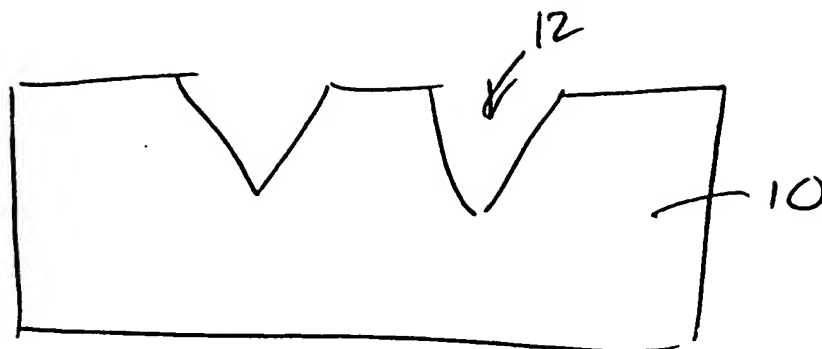


FIG. 1A
PRIOR ART

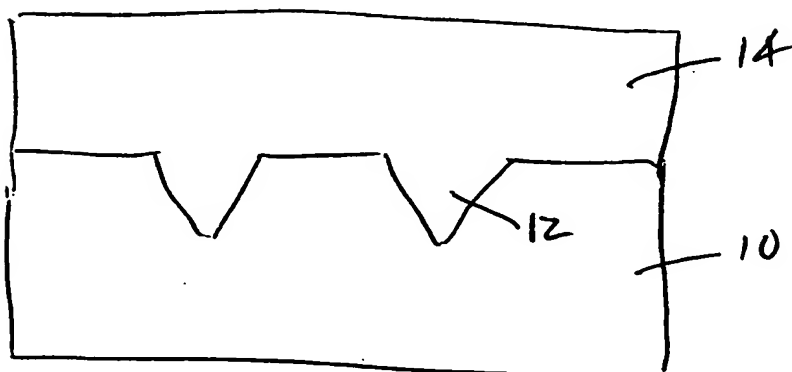


FIG. 1B
PRIOR ART

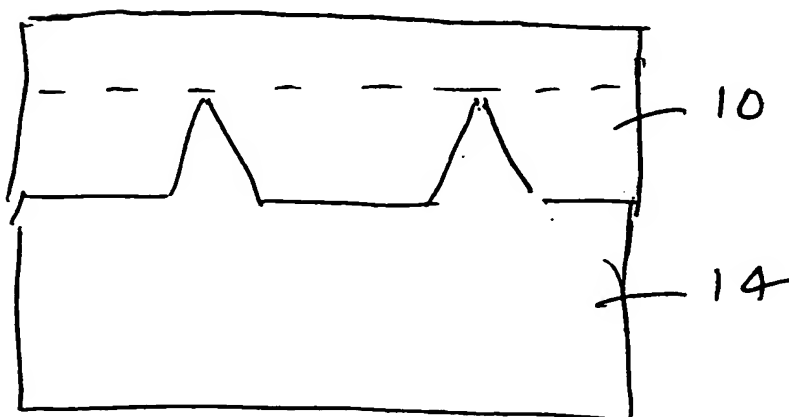


FIG. 1C
PRIOR ART

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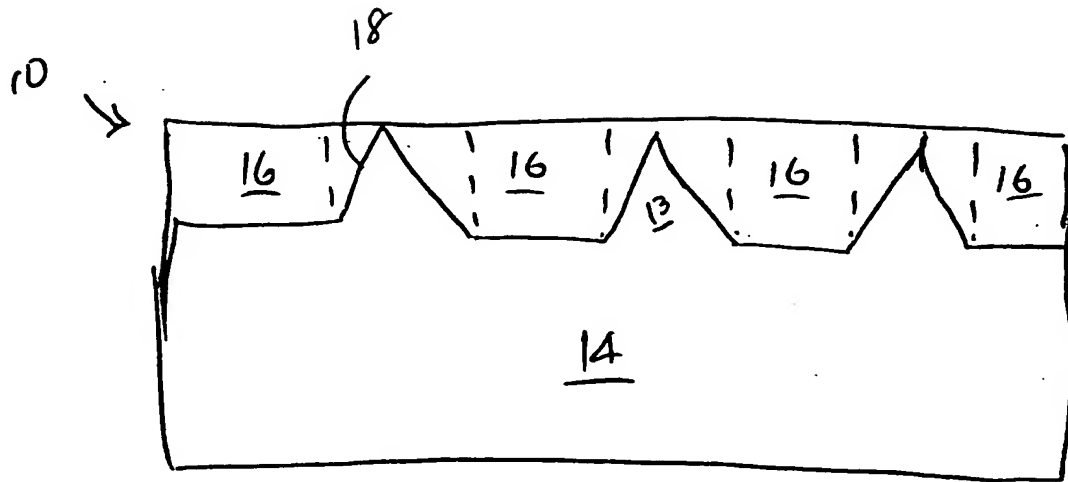


FIG. 1D
PRIOR ART

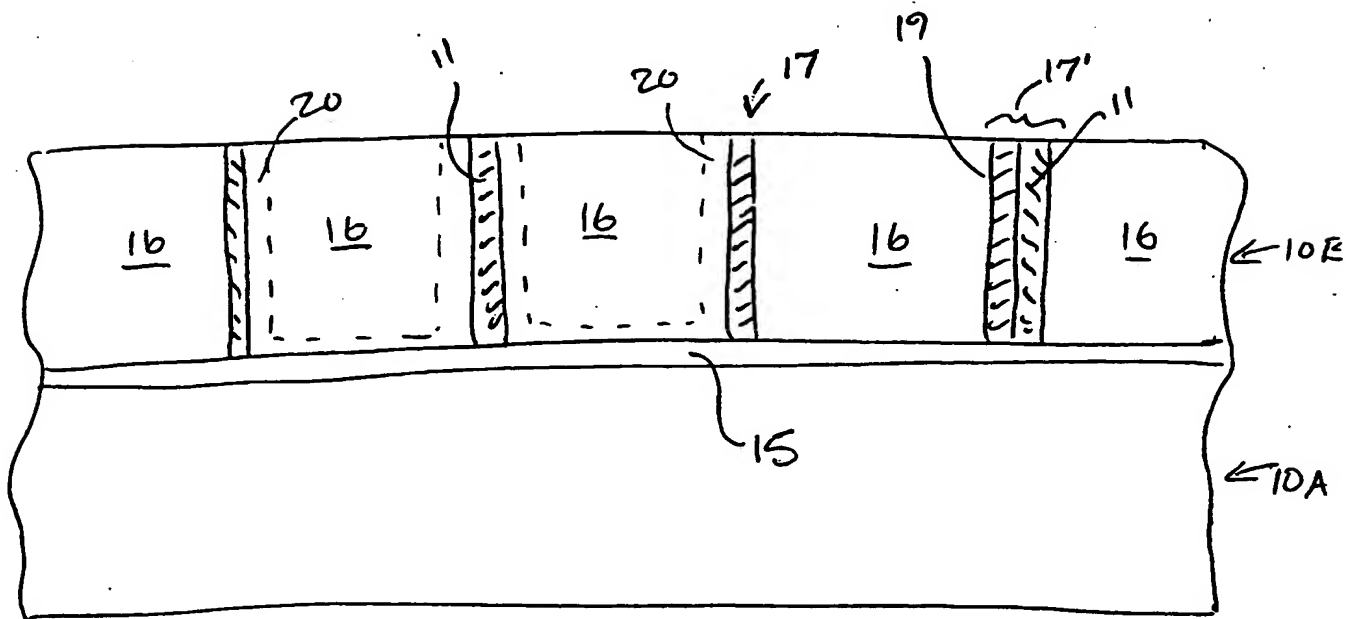


FIG. 1E
PRIOR ART

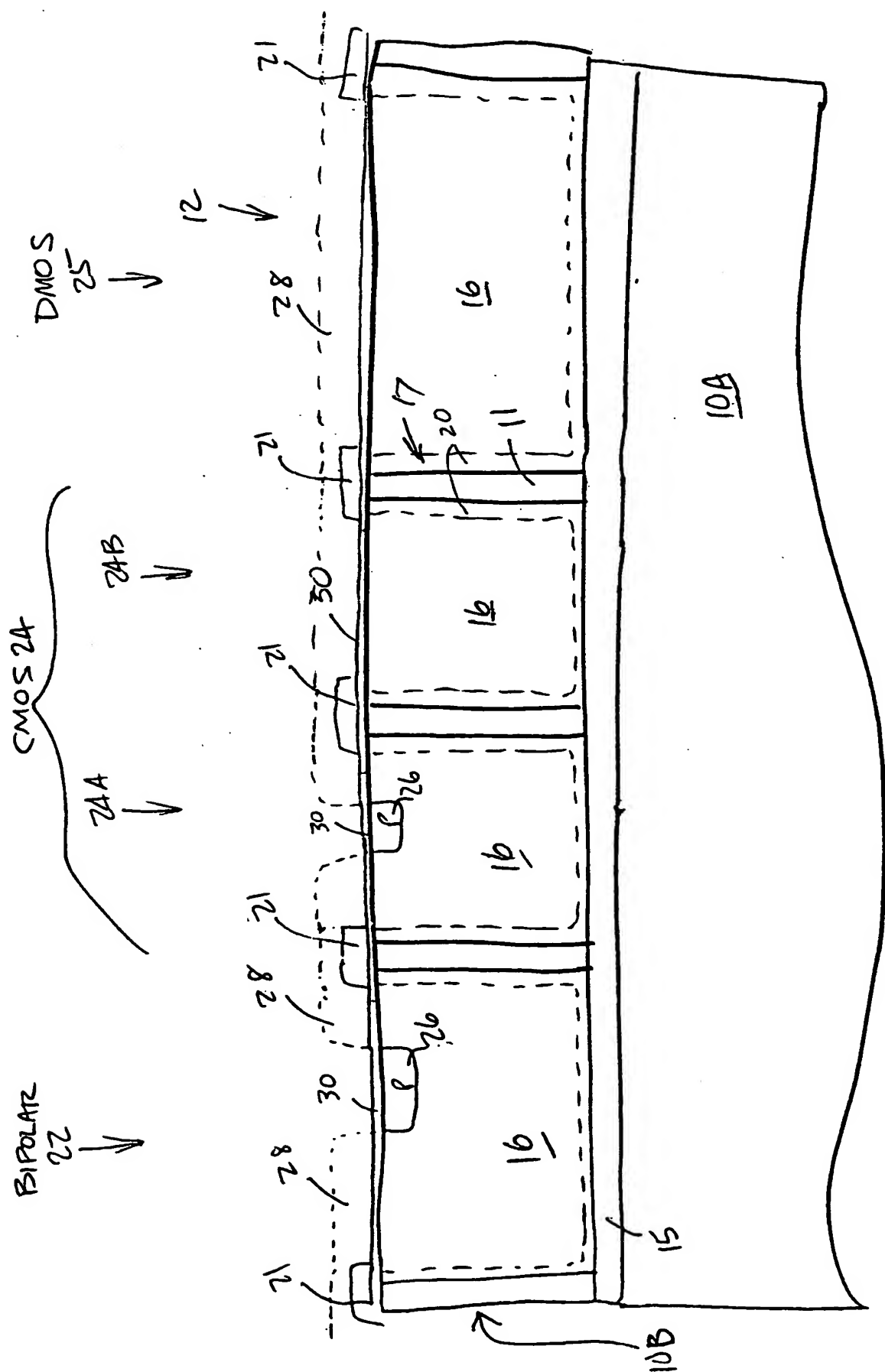


Fig 2

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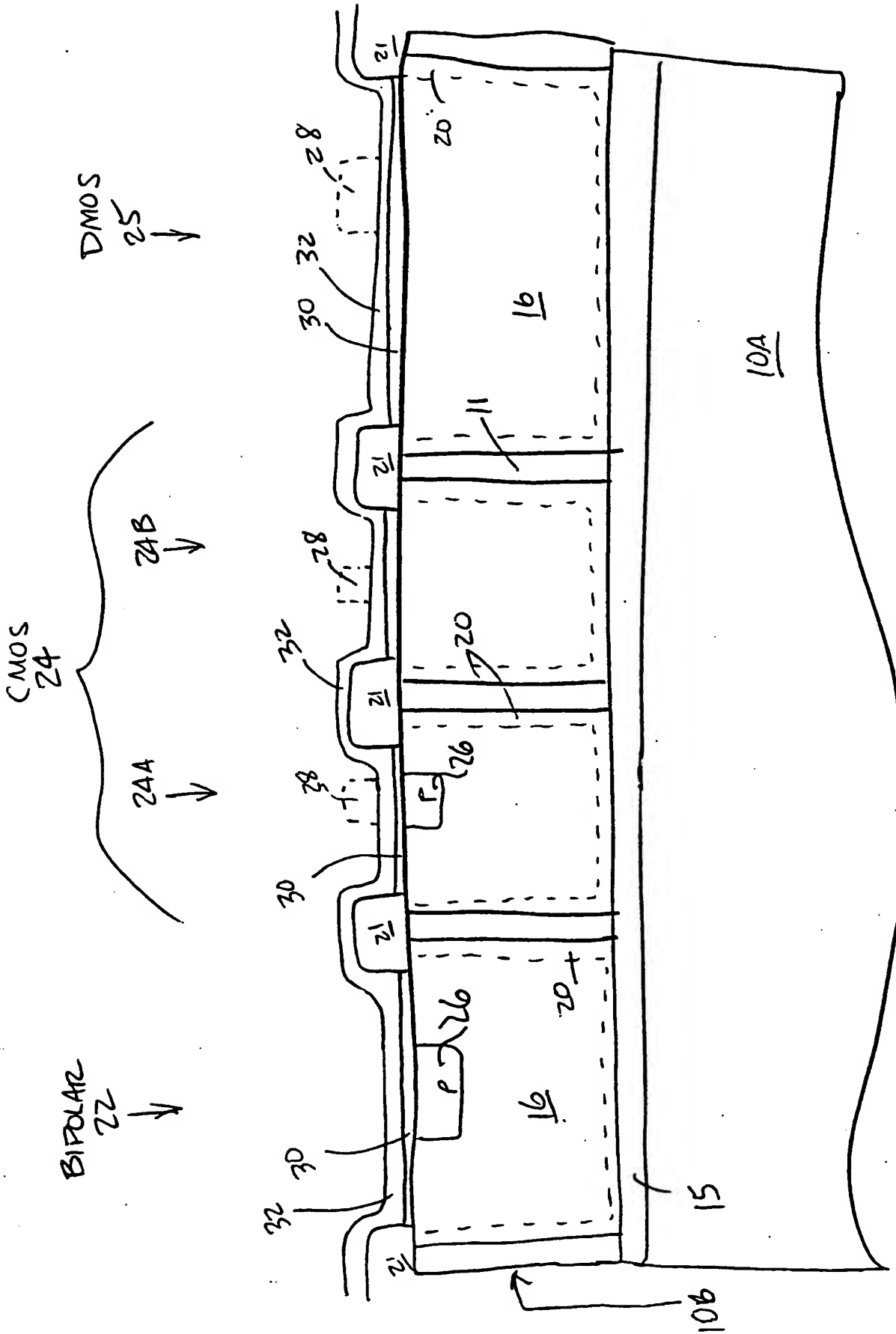


FIG. 3

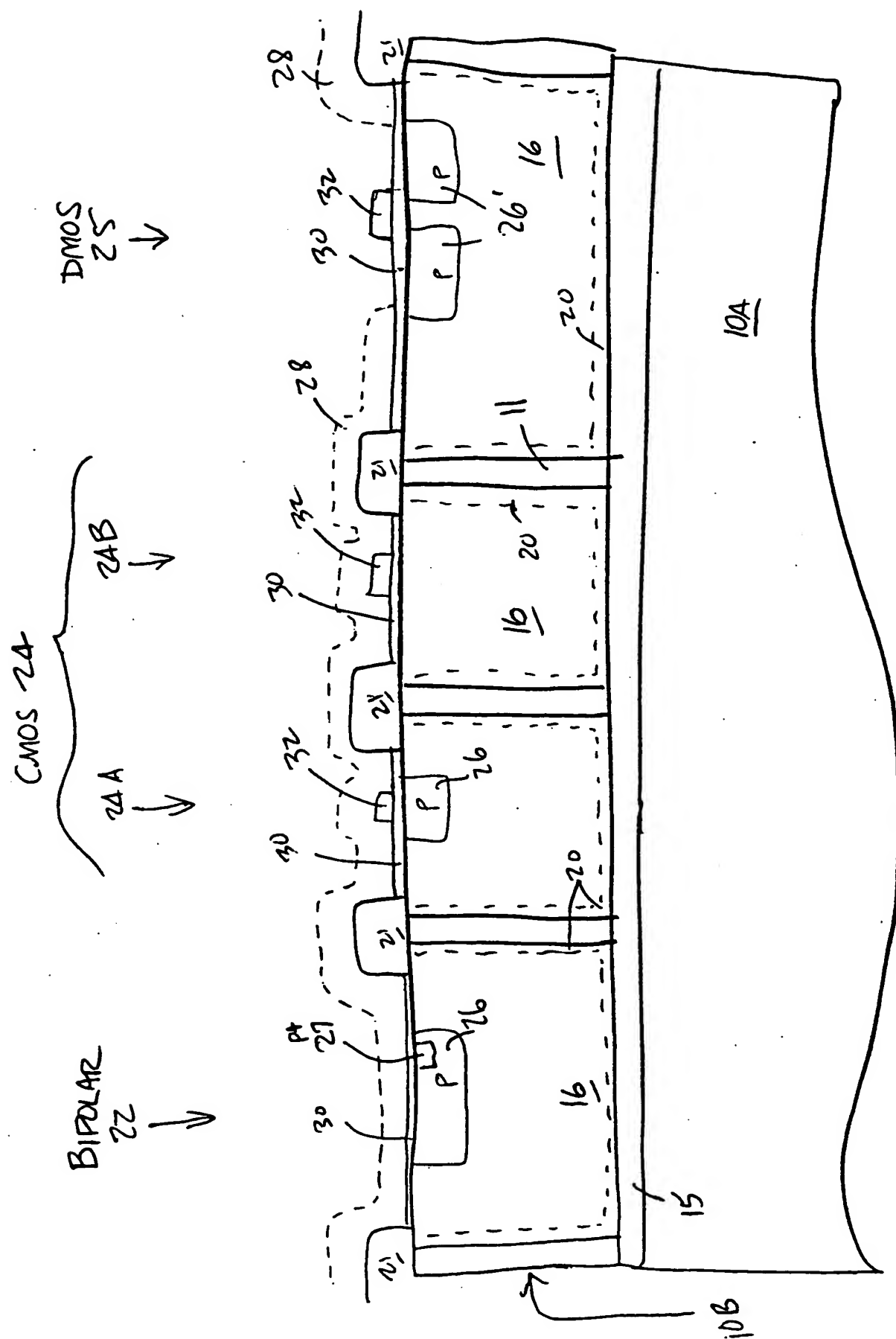


Fig. 4

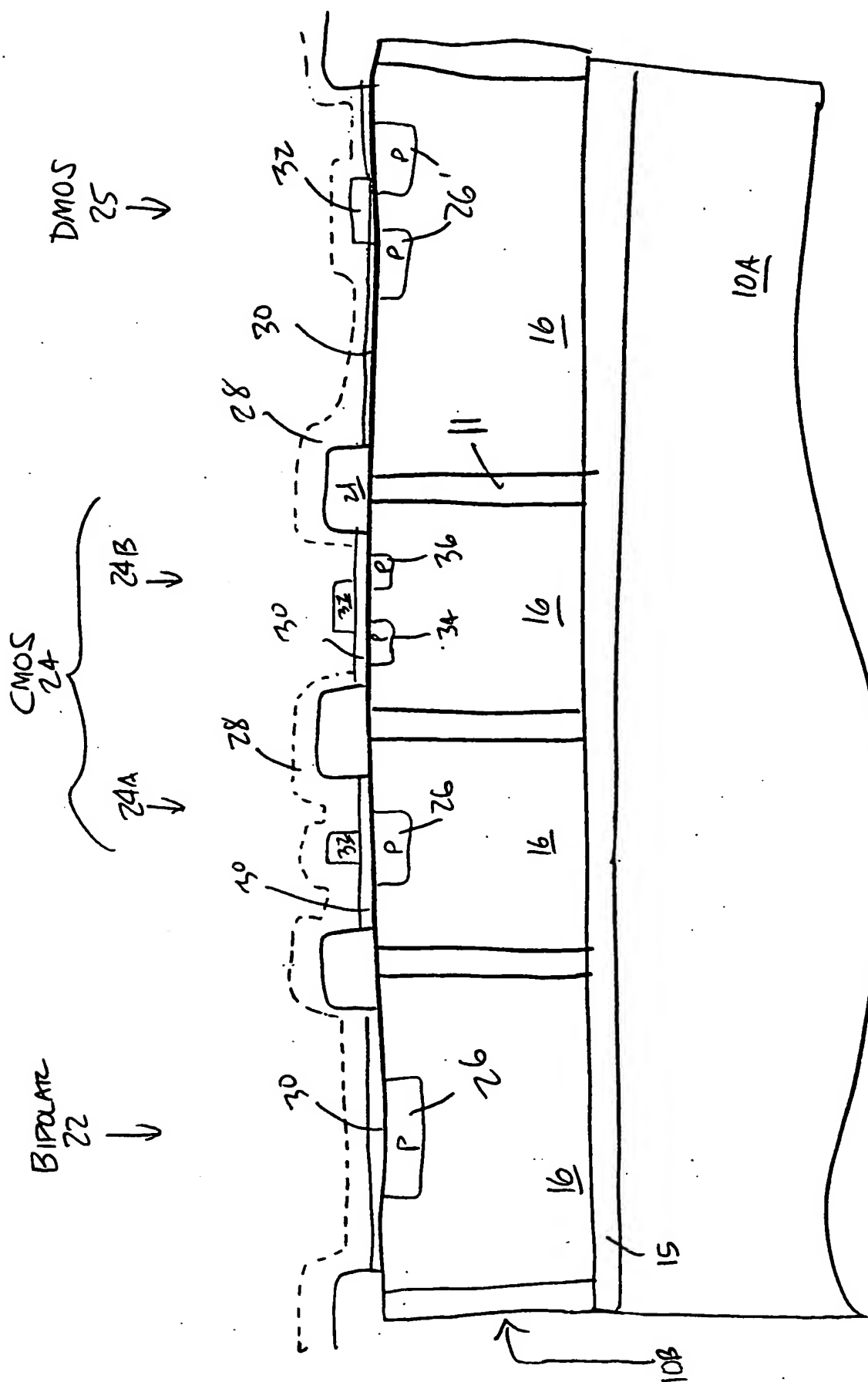


Fig. 5

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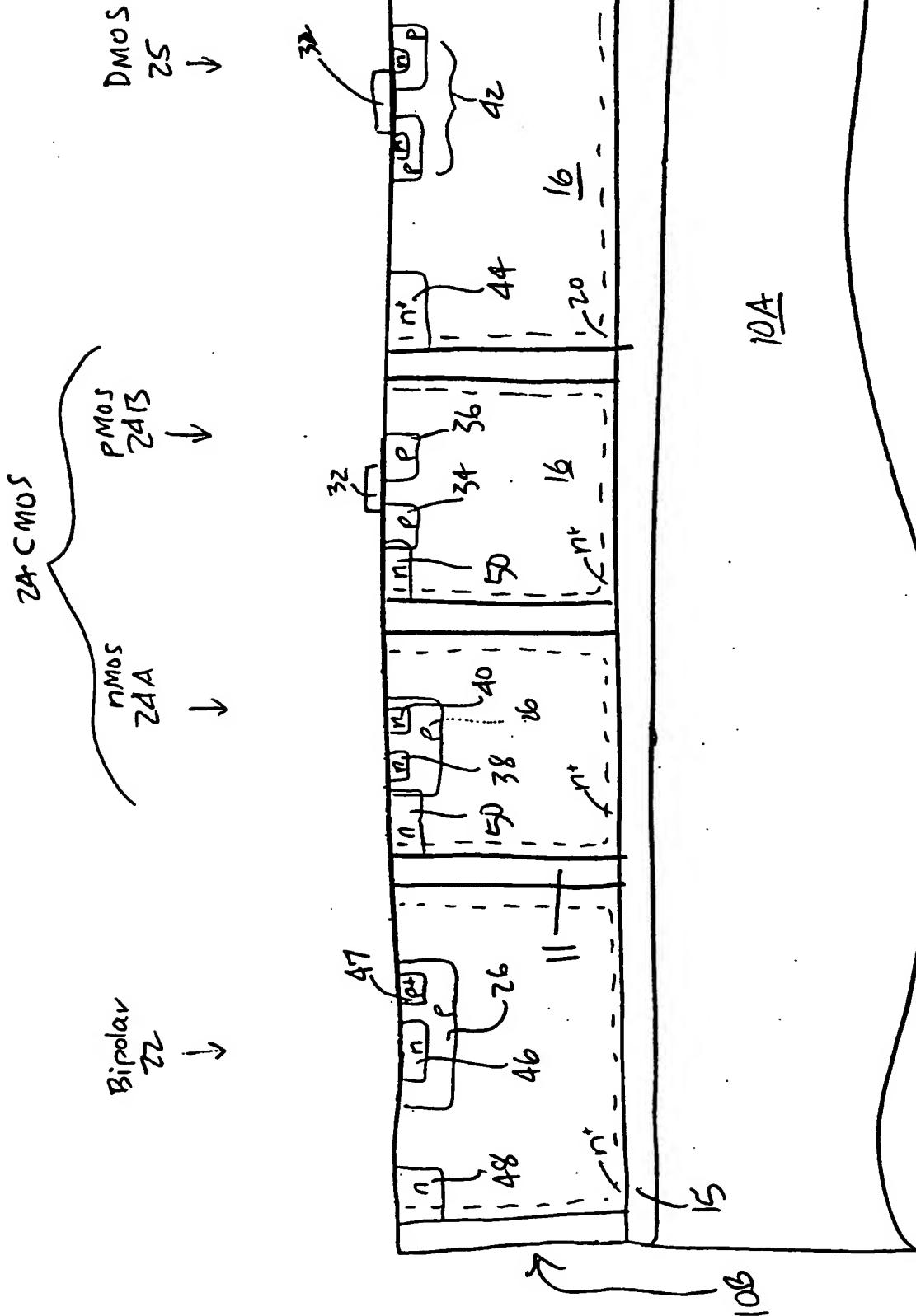
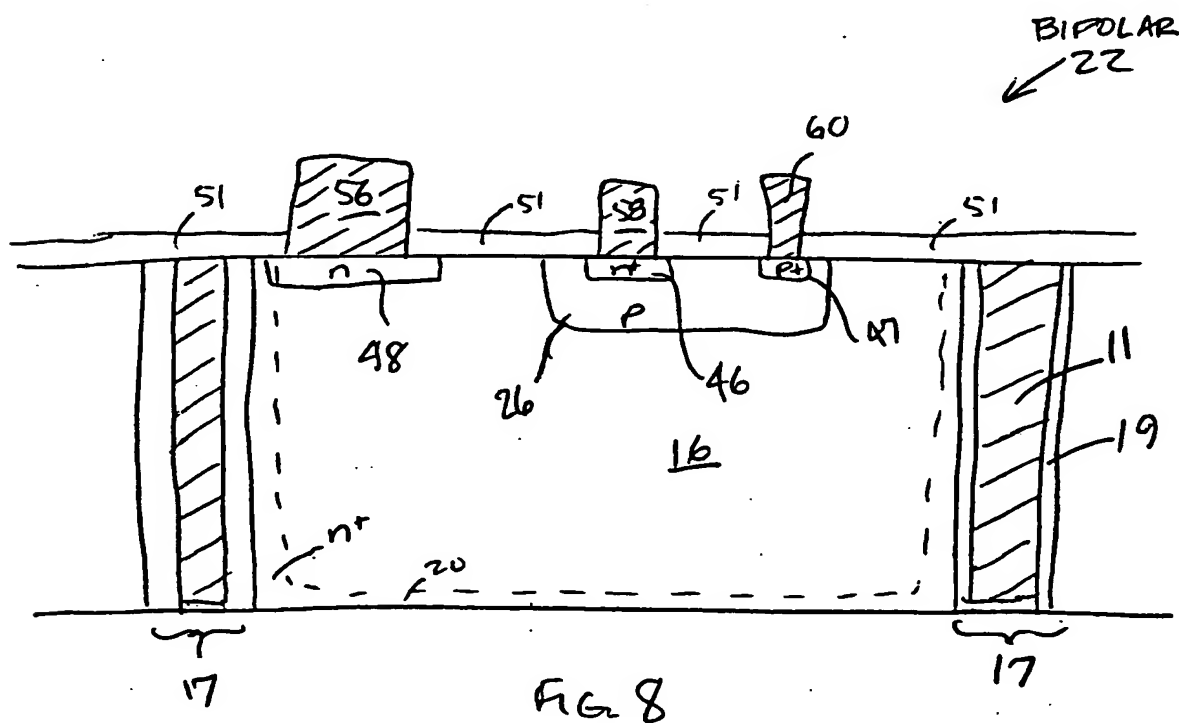
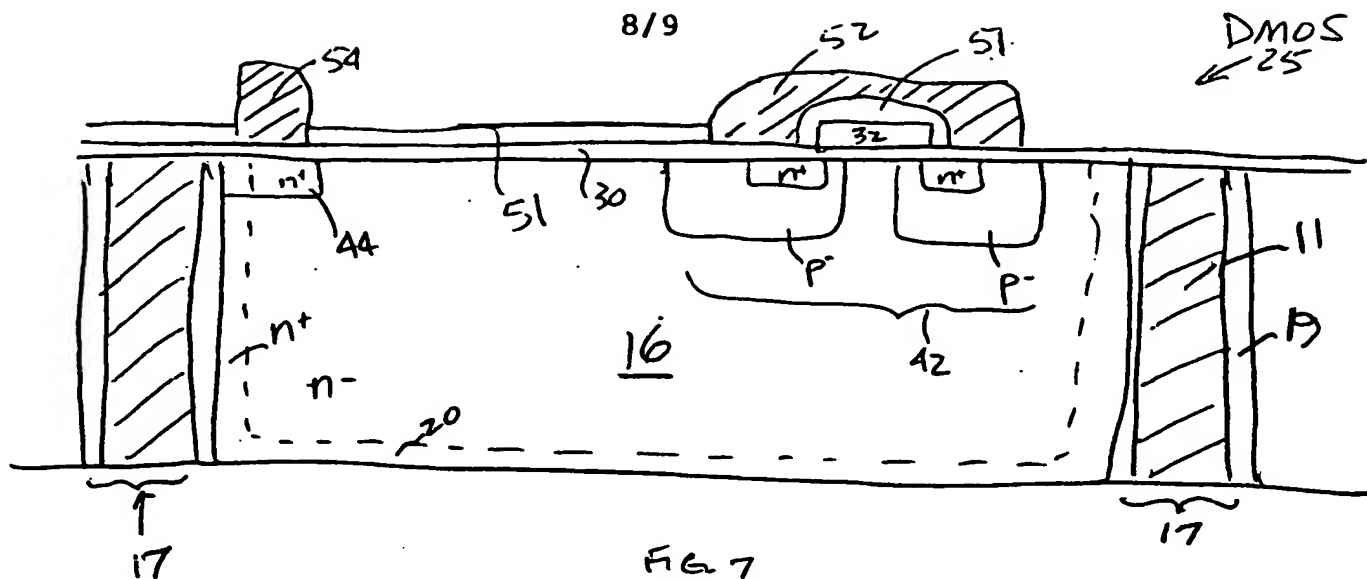


FIG. 6



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CMOS 24

nMOS 24A ↓

PMOS 24B ↓

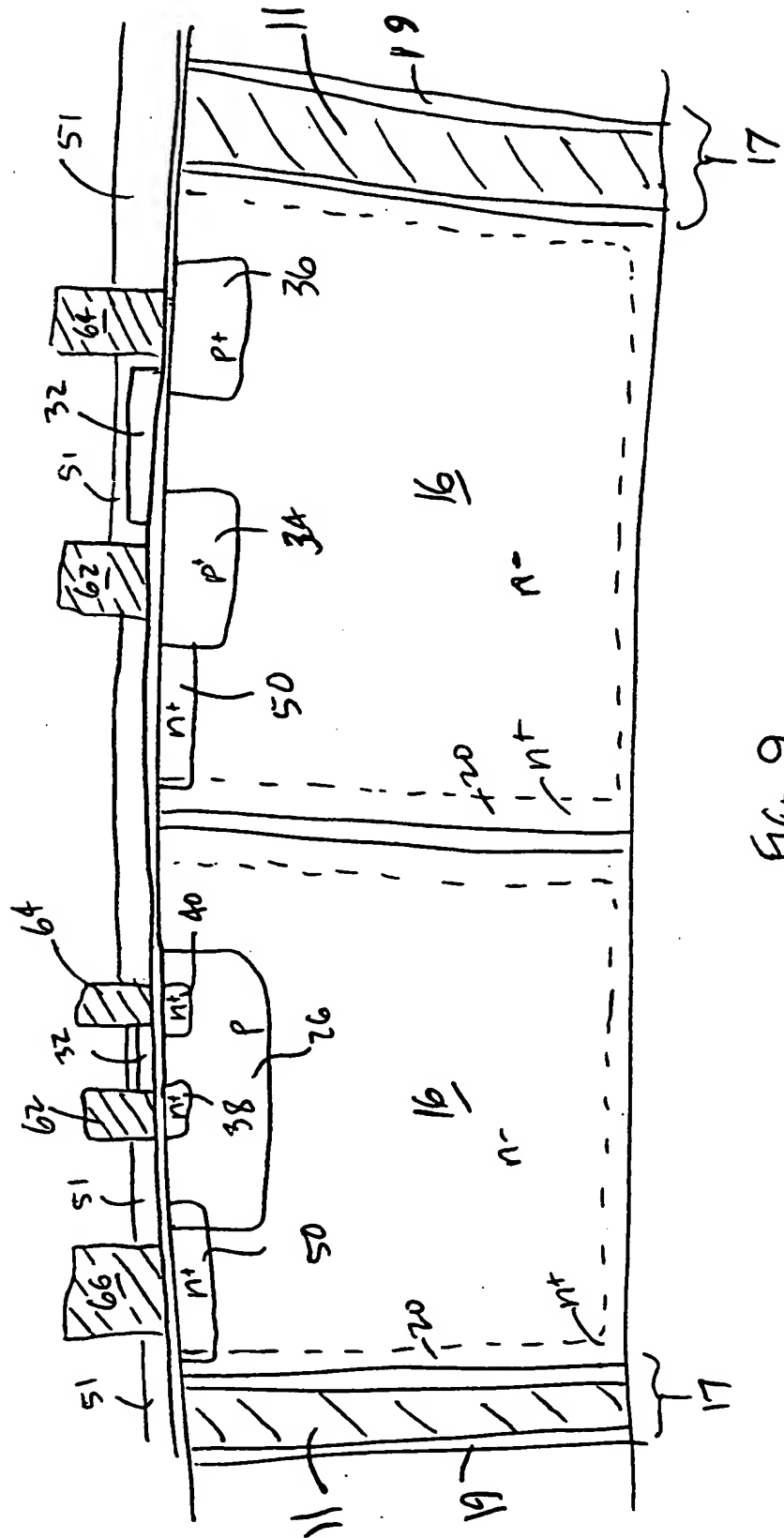


FIG. 9

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US00/09991

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : H01L 29/74, 31/111, 21/8238, 21/8249
US CL : 257/168, 338, 339, 337; 438/207, 202, 234

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 257/168, 338, 339, 337, 328, 335, 350, 356, 357, 378, 409; 438/207, 202, 234

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Neamen-Donald, A. Semiconductor Physics & Devices, second edition. McGraw-Hill Companies, Inc. 1992 and 1997.

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
USPTO APS IEEE, Search terms: "CMOS" and ("BJT" or "NPN" or "PNP" or "bipolar") and ("breakdown voltage" or "high voltage")

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X,P	US 5,939,755 A (TAKEUCHI et al.) 17 August 1999 (17.08.1999), column 1, lines 13-14, column 4, lines 58-63, column 6, lines 63-64, column 7, lines 31-48 and column 12, lines 10-59.	1-17
X — Y	US 5,841,197 A (ADAMIC, Jr.) 24 November 1998 (24.11.1998), column 2, lines 11-24, column 4, lines 12-15, and 59-62, column 20, lines 49-55, column 21, lines 34-38, and column 22, lines 56-65.	1-4, 15-17 — 5-14
Y	US 4,916,085 A (FRISINA) 10 April 1990 (10.04.1990), see entire document.	5-14
Y	US 5,171,699 A (HUTTER et al) 15 December 1992 (15.12.1992), see entire document.	5-14
Y	US 5,181,095 A (MOSHER et al) 19 January 1993 (19.01.1993), see entire document.	5-14

☐ Further documents are listed in the continuation of Box C.

☐ See patent family annex.

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Date of the actual completion of the international search

23 June 2000 (23.06.2000)

Date of mailing of the international search report

19 JUL 2000

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